Comparative Immunology, Microbiology and Infectious Diseases 36 (2013) 559–566

Contents lists available at ScienceDirect

Comparative Immunology, Microbiology and Infectious Diseases

journal homepage: www.elsevier.com/locate/cimid

Review

Impact of climate change in the epidemiology of vector-borne diseases in domestic carnivores

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ARTICLE INFO

Article history:
Received 3 June 2013
Received in revised form 26 June 2013
Accepted 17 July 2013

Keywords:
Vector borne diseases
Climate changes
Companion animals
Europe

ABSTRACT

Vector-borne diseases are medically important in humans and animals but were long considered tropical and known to first affect production animals. This is no longer true and we can see today that they are common in domestic animals and that they are also present in temperate countries, especially in Europe. In recent years, an increase in the diagnosis of vector borne diseases among humans and animals has been observed, which may partly due to the development of diagnostic tools. Their study requires exchanges and collaborations between the many actors involved, especially since the epidemiology seems to be constantly evolving. The veterinary practitioner is the first one to notice the emergence of cases and to implement prevention measures. He also acts as a sentinel to alert epidemiologists. Many factors can explain the epidemiological changes, i.e. all human factors, such as the increase in commercial transportation, but also owners traveling with their pet during the holidays, the development of "outdoor" activities, the increase of individual housings with gardens; to these human factors must be added the ignorance of the risks, linked to animals in general and to wildlife in particular; then the environmental changes: forest fragmentation, establishment of parks; the increase of wild mammal populations (deer, carnivores, rodents, etc.); finally, climate changes. Climate change is a reality which may explain the increase of density of arthropod vectors, but also of their hosts, changes in periods of activity and variations in geographical distribution. The authors show the proof of the climate modifications and then explain how it has an impact in Europe on ticks, mosquitoes, sandflies and even fleas. They conclude on the practical consequences for veterinary practitioners, especially with the diagnosis of parasitic diseases or diseases in areas where they usually do not occur. However, not any epidemiological modification should be linked to climate change, since many other factors are involved and often even overriding.

Contents

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0147-9571
http://dx.doi.org/10.1016/j.cimid.2013.07.003

1. Introduction

Vector-borne diseases seem to be “fashionable” when we look at the number of journals and publications that relate to them. They are medically important in humans and animals but were long considered tropical and known to first affect production animals. This is no longer true and we can see today that they are common in domestic animals and that they are also present in temperate countries, especially in Europe [1].

Their interest and importance are increased by the fact that most vector-borne diseases, including bacterial and viral, are zoonotic diseases [2]. Especially in recent years, an increase in the diagnosis of rickettsial diseases among humans and animals has been observed in the Unites States and in Europe [3,4]. The development of the diagnostic tools and the easiness to have access to them may also play a role in the increased diagnosed of vector borne diseases. Their study requires exchanges and collaborations between the many actors involved, such as veterinarians, physicians, epidemiologists, but also entomologists, meteorologists, experts in geographic information systems, etc., especially since the epidemiology of vector-borne diseases seems to be constantly evolving [5]. The veterinary practitioner is the first one to notice the emergence of cases and to implement prevention measures. He also acts as a sentinel to alert epidemiologists [6].

Many factors help to explain the epidemiological changes, they were summarized in 2005 by Harrus and Baneth [7]:

1. First of all human factors, such as the increase in commercial transportation, but also owners traveling with their pet during the holidays, the development of “outdoor” activities, the increase of individual housings with gardens. To these human factors must be added the ignorance of the risks, linked to animals in general and to wildlife in particular, among the actors of rurbanization[1] and neo-rural dwellers;
2. Then the environmental changes: forest fragmentation, establishment of parks, various developments;
3. Without a doubt, the increase of wild mammal populations (deer, carnivores, micromammals, etc.);
4. And finally, climate changes.

Statements 1, 2 and 3 explain the increase in the number of reservoirs of vectors or pathogens and the increase in the risk of contact with humans and domestic animals. Let us take the example of the strong interest in Siberian chipmunks in the 1980s. These rodents were very popular and sold in all pet stores in France. Unfortunately noisy and capable of biting, they were released to the wild. They proliferated in certain forests and sometimes supplanted our red squirrel or voles, with which the competition is strong.

However, Siberian chipmunks are obviously the host of choice for tick nymphs and they are also responsive to *Borrelia*. A recent study thus shows their role in the maintenance, or even in the increasing risk for humans, of Lyme disease in the Melun-Sénart forest in the suburbs of Paris [8].

Many factors are therefore involved in the increased risk of developing vector-borne diseases. Climate changes are added to those factors. Climate change may explain the increase of density of arthropod vectors, but also of their hosts, changes in periods of activity and variations in geographical distribution.

2. Evidence of climate change

Climate changes are no longer being debated, only the mechanisms responsible for them are a matter of controversy [9,10]. Global warming has accelerated over the last hundred years (Fig. 1) with an average gain of 0.74 °C in 100 years [11]. It is not uniform, affecting the Northern more than the Southern hemisphere, and is definitely not characterized by “more beautiful summer days”. The result is rather a reduction in the number of cold days, thus a shorter winter period, often alternating with milder periods. Rainfall may be higher in certain areas and lower in others, for instance, the annual distribution may be: more winter precipitation and increased summer drought in Mediterranean areas.

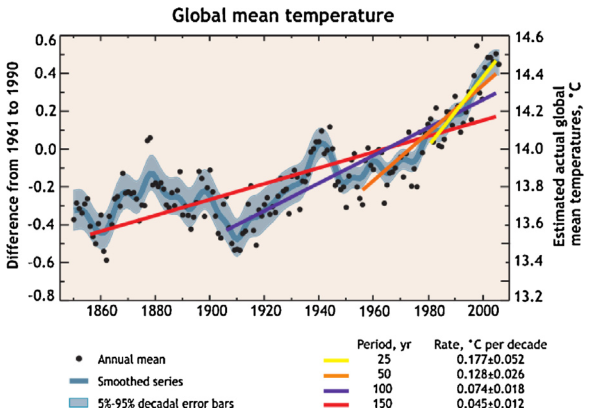

Fig. 1. Exponential increase of global temperature since 1860 [9].
Source: Reservoir Rodents. PLoS ONE; www.plosone.org, 2013, 8(1), e55377.

[1] A term coined in the 1970s from combining the words rural and urban to describe the process of “return” or “escape” of city dwellers to the countryside. Rurbanization is the transformation of rural communities around the city and is characterized by land-use changes. Lands (especially farmlands) are used for new constructions for residential purposes, services or industrial activities, in direct relation with the city. In the end, it is primarily a process of spatial extension of the city.

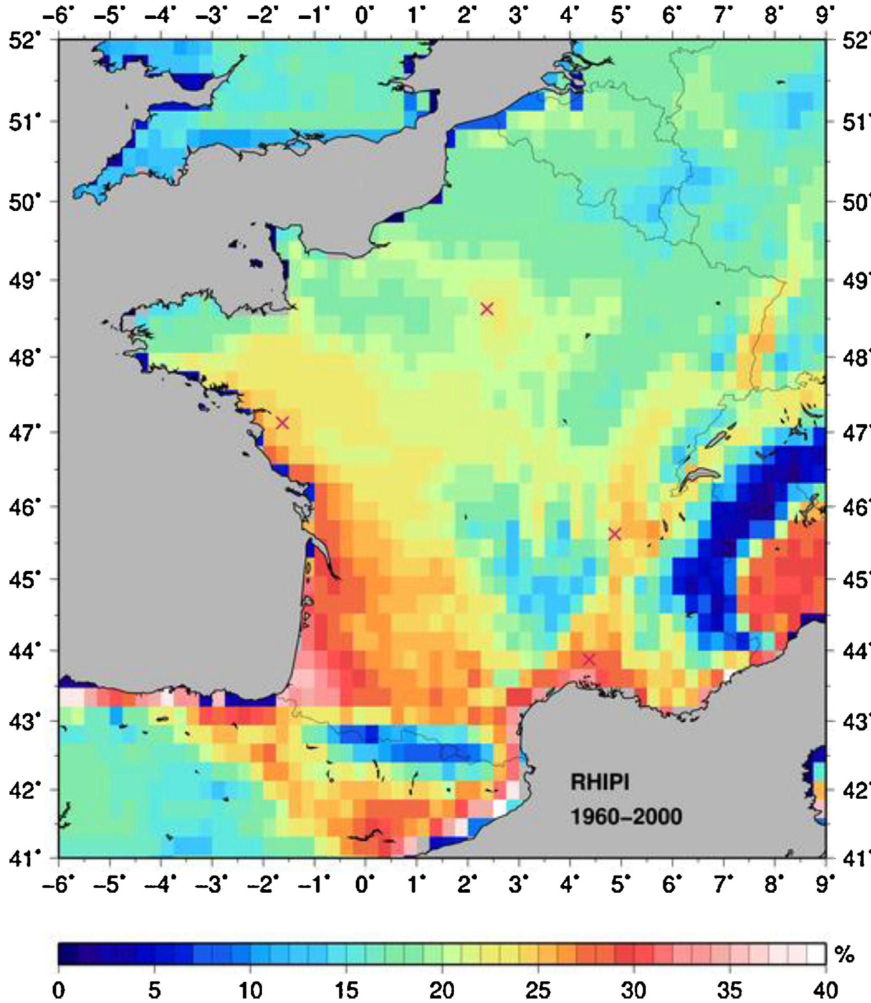

Fig. 2. Areas of distribution where *Rhipicephalus sanguineus* can biologically survive and develop (index >25%, in orange and red), based on an average of 40 years of real weather data between 1960 and 2000 [14].

Changes in average climate conditions are observed between regions. If the conditions in Western and Northern Europe were to be described, those would be shorter and less severe winters and wetter summers. These changes can have a direct impact on the survival and development of arthropod vectors, which today is well demonstrated among ticks but also in some mosquitoes.

3. Impact of climate change on ticks

The impact of climate change in Europe is most pronounced among ticks and probably their hosts [12]. Evidence is not only provided by models but also especially by field studies.

The use of a meteorological model [13] and biological data regarding the brown dog tick, *Rhipicephalus sanguineus*, applied to Europe since 1960, clearly indicates that this tick species, endemic in Mediterranean regions, can now survive and develop in the Southwest of France up to Nantes and in the Southeast of France up to Lyon [14] (Fig. 2). A sporadic occurrence of these ticks in Belgium and in the Netherlands, as well as indigenous cases of canine ehrlichiosis, confirm their spread from the Mediterranean Basin to more northerly latitudes.

Moreover, the climatic zone favorable for their reproduction has expanded by 669% since the 1960s in Europe [14]. In addition to the South of France, Italy and Spain, *R. sanguineus* is now endemic in the Balkans, Romania, Bulgaria and has been reported in the South of Hungary [32].

Dermacentor reticulatus, the tick vector of canine babesiosis caused by *Babesia canis*, is present in 2/3 of the French territory [15]. It is clearly spreading to the East, favoring milder winters (Fig. 3). It has now been reported in Belgium [16], the Netherlands, where cases of canine babesiosis have become more and more common. It has also been observed in Germany, Czech Republic, Slovakia, but also in the area of Moscow [17,18]. In Slovakia, field studies showed that its limited area of presence had gained 200 km north since the 1970s, as well as 300 m in altitude [19]. These studies conducted in continental Europe have shown that shorter winters have a direct impact on the ecology of ticks. But we nevertheless must keep in mind

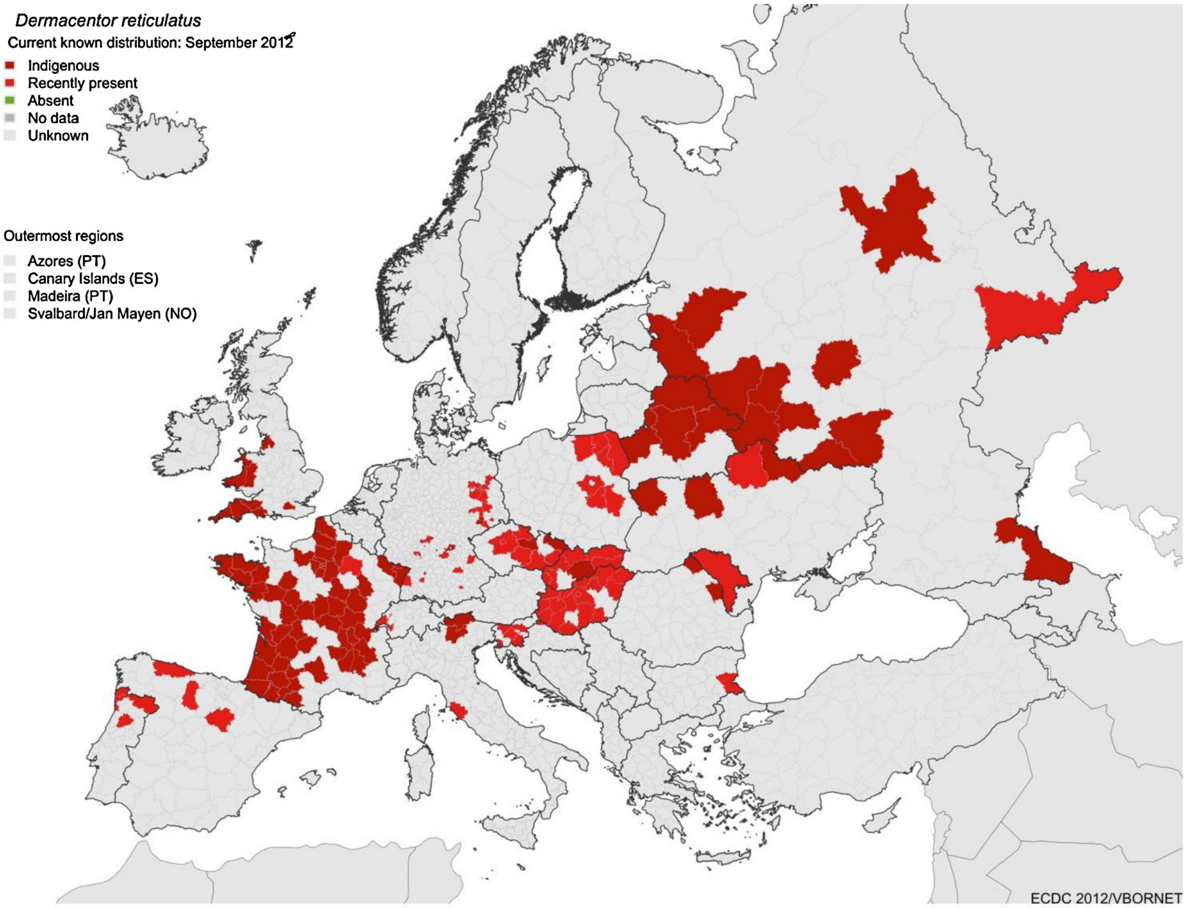

Fig. 3. Distribution of *Dermacentor reticulatus*, exophile tick of dogs and horses.
Source: European Center for Disease Control (www.ecdc.europa.eu), September 2012 [28].

that climate changes are currently still limited and that other human-induced factors co-exist.

Regarding *Ixodes ricinus*, the forest tick, the most common among hard ticks in Europe, its presence and density are obviously related to the plant cover, but also to the density of its hosts: micromammals for larvae and nymphs and large mammals (deer, wild boar, foxes and even bovine and dogs) for adult ticks [20]. However, weather conditions play a significant role in the survival and activity of rodents, as well as in periods during which ticks are active, on the lookout for hosts in vegetation.

The decrease of winter days with temperature below a certain cut-off was identified by several authors as a key factor in the increased density of ticks of the genus *Ixodes* as well as their questing activity during winter period [21–23]. Usually the number of days with negative temperature is studied. Dautel studied the questing activity of *I. ricinus* in Berlin forests from October 2006 to March 2007 [21]. Using larva, nymph and adult ticks identified and put in plots in forest, he demonstrated that they maintained their activity of questing for hosts during the entire winter period when they were dormant in the previous years. The Swiss team of Lise Gern showed that same impact of increased winter temperatures on the distribution of ticks in the Alps around Neuchâtel, and especially the extension of the area of presence in altitude, with limits increasing from 620 to 1070 m in some mountain ranges [22]. A similar study on the number of days of activity of ticks, their density and the number of days with negative temperatures was carried out in Scandinavia by Lindgren from the year 2000 [23]. Lindgren et al. [23] studied 5 areas in Sweden and counted the number of days with average temperatures below 12 °C, between −12 and −10, −10 and −7 and from −7 to 0 °C. Lindgren compared the number of days in these categories in the 80 years to the 90 years and found in some areas 40 days less with temperature below −12 °C and 20 days more with temperature above −7 °C in winter period.

Thus, by observing the activity of the three main tick vectors encountered in Europe over relatively short periods of time, changes are noted. They are all associated with an increase in activity and thus in the risk of transmitting pathogenic agents.

4. Impact of climate change on mosquitoes and sandflies

Culicidae mosquitoes are present all over Europe, including in the harshest climates (Scandinavia, Siberia).

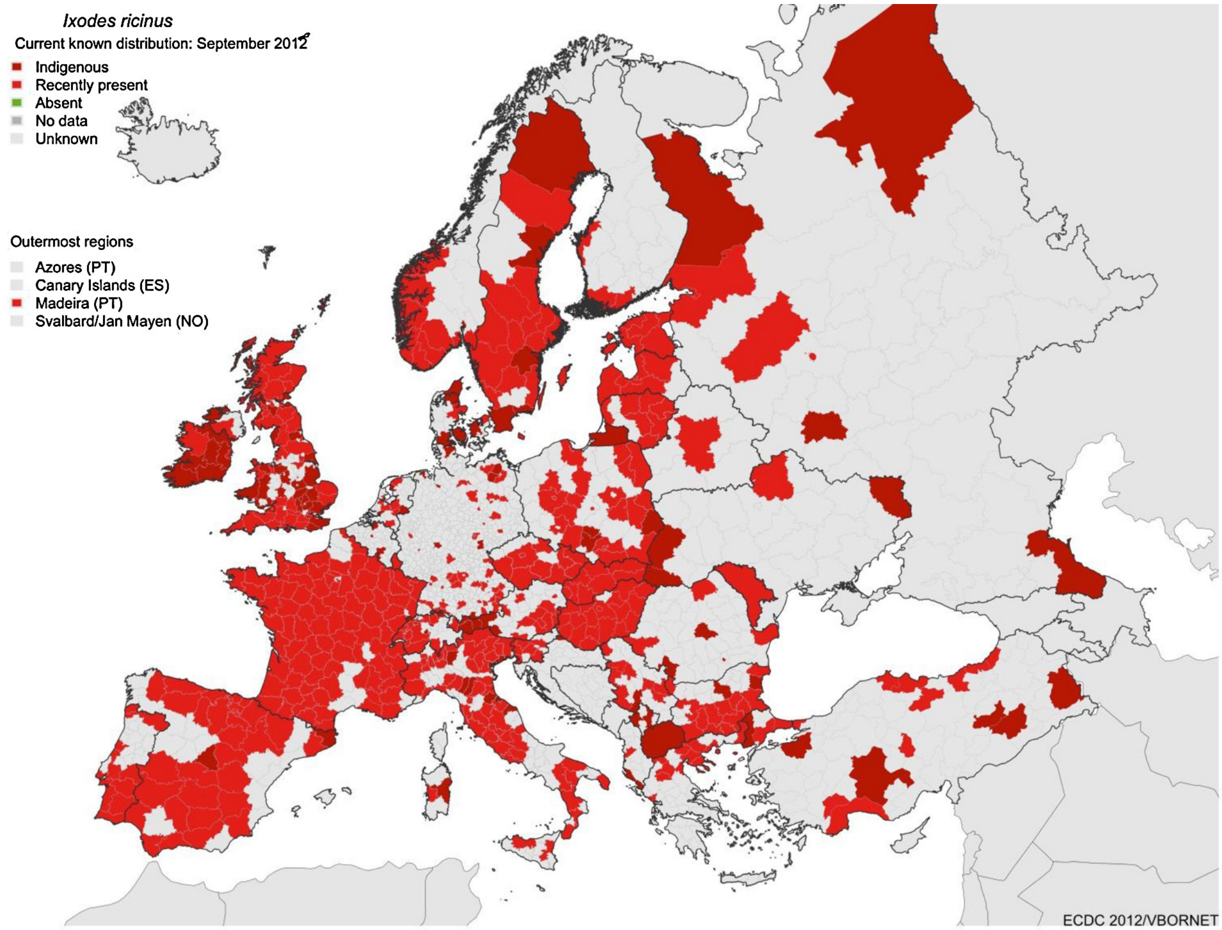

Fig. 4. Distribution of *Ixodes ricinus*, the forest tick.
Source: European Center for Disease Control (www.ecdc.europa.eu), September 2012 [28].

The risk of transmission of pathogenic agents by mosquitoes is not linked to their mere presence but to:

1. Vector competence (ability to complete the cycle of the pathogenic agent within the vector, followed by transmission);
2. Meteorological conditions enabling:
a. The pathogen to complete its extrinsic cycle during the vector's period of activity;
b. The vectors to be active and abundant enough (with the role of environmental conditions);
3. The presence of the pathogen and of at least one reservoir.

Climate change may be reflected by an increase in the number of days of activity per year. This is what Genchi, Rinaldi and their team studied in Italy and Europe for *Dirofilaria immitis* [24,25]. The cycle is related to the presence of microfilaremic dogs and to the possibility for them to be bitten by mosquitoes, and for the infesting larvae to develop within the mosquitoes. Larval development lasts 8–20 days, 14 days in average, but is temperature-dependent and mosquito-dependent. It does not occur below 14 °C. The authors used an index named "*Dirofilaria* or heartworm Development Unit". The total environmental heat required for development may be expressed in terms of degree-days in excess of this threshold of 14 °C (heartworm development units, HDUs). The seasonal HW transmission model originally formulated by Slocombe et al. (1989) in Canada and reevaluated by Lok and Knight (1998) in the United States assumes a requirement of 130 HDUs for larvae to reach infectivity and a maximum life expectancy of 30 days for a vector mosquito (in [24]). Therefore, it is assumed by the models that 130 DUs are required per year for the parasite to maintain itself in one same area. As an example, 10 consecutive days with an average temperature of 20 °C correspond to 60 HDUs ((20 °C – 14 °C) × 10). The authors then observed climate changes that have occurred in Europe over the past 15 years, on 5475 weather stations and integrated over 19 million temperature values (Fig. 4). Thus, it seems that heartworm disease can now be maintained beyond the Mediterranean region, based only on the biology of vectors and parasites and the evolution of temperatures (Fig. 5).

In fact, heartworm disease is more commonly diagnosed in the Balkans, South of Hungary and also South of Russia. However, in order for a new outbreak to occur, there has to

Fig. 5. Map of areas of potential development of *Dirofilaria immitis* [25].

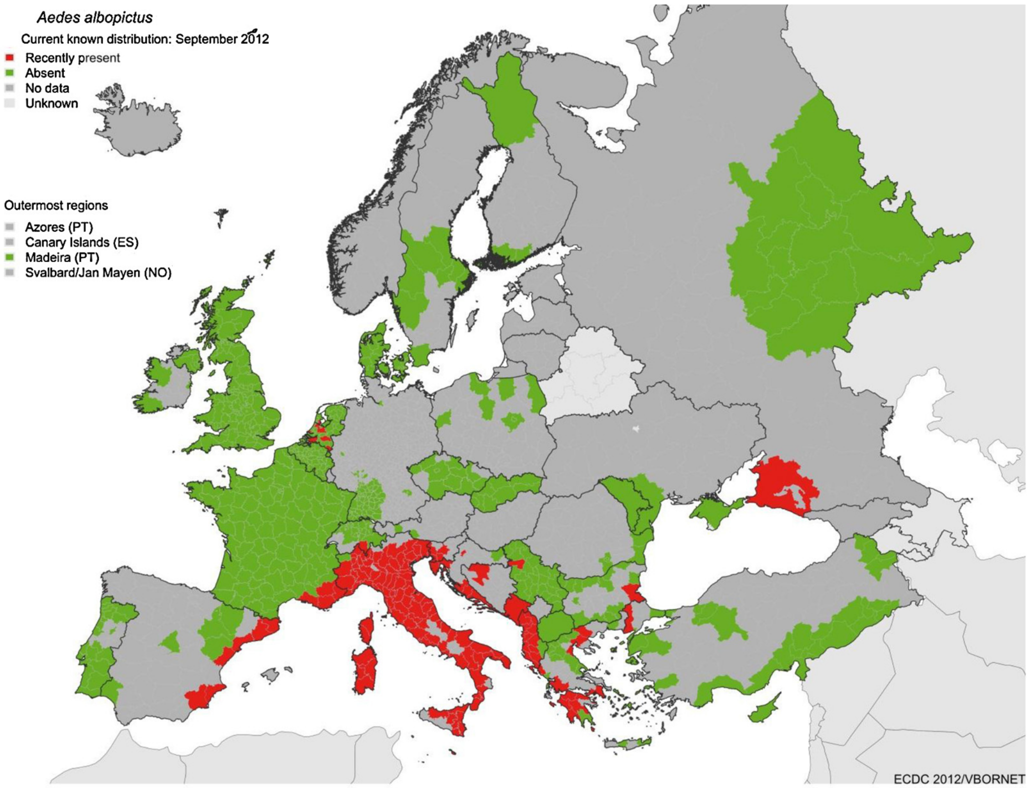

Fig. 6. Distribution of *Aedes albopictus*, the “tiger mosquito”.
Source: European Center for Disease Control (www.ecdc.europa.eu), September 2012 [28].

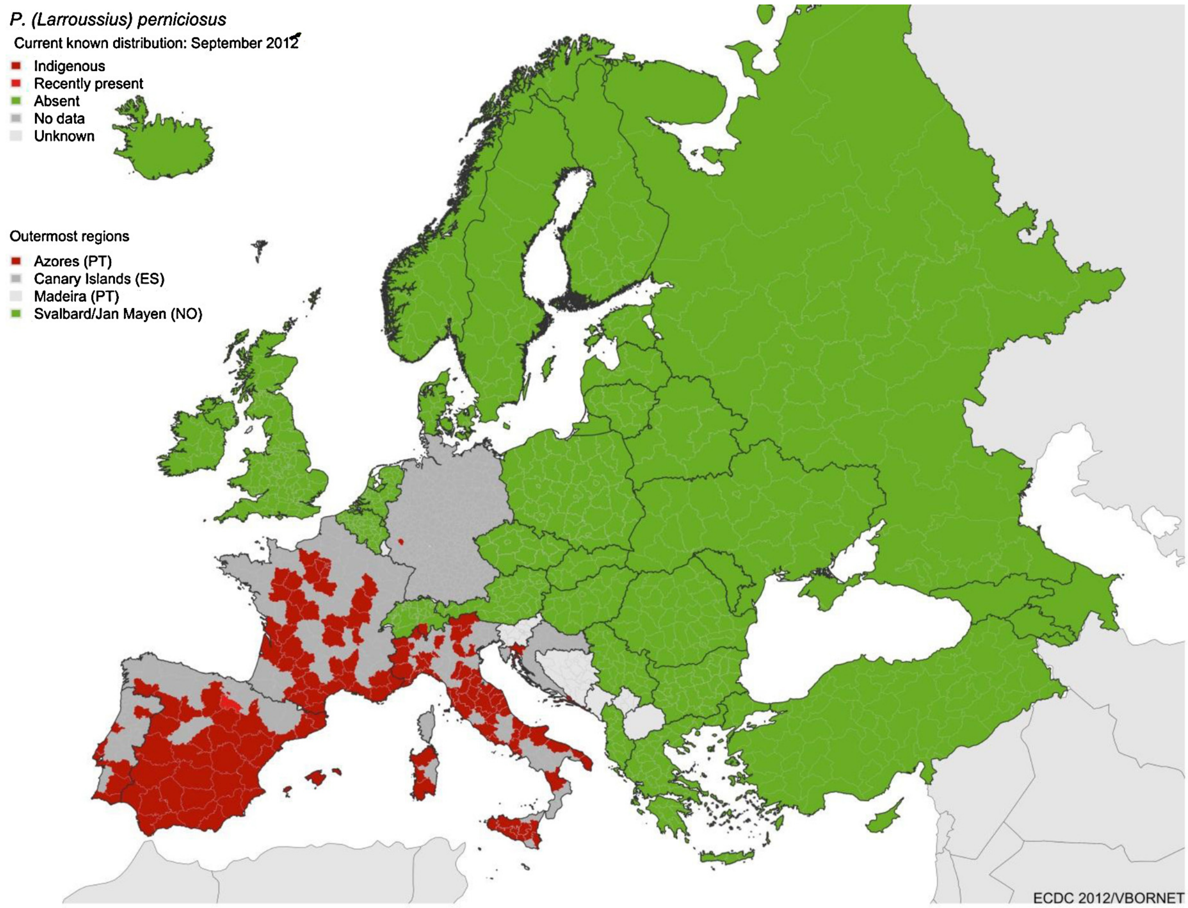

Fig. 7. Distribution of *Phlebotomus preniciosus*, main vector of canine leishmaniosis caused by *Leishmania infantum* in Europe. *Source*: European Center for Disease Control (www.ecdc.europa.eu), September 2012 [28].

be a sufficient number of infested dogs present in one area. The appearance of a new vector may also be a possibility.

This is actually happening now with the expansion across Europe of the tiger mosquito, *Aedes albopictus*, which was imported from Asia to Italy in 1990 through a trade of old tires for the remolding industry [26]. Today, it has been reported as far as in the Netherlands. Arriving from Italy to France via Nice, it is now present in approximately 1/3 of the southern French territory, up to Lyon as described by the European Center for Diseases Control, ECDC [27,28] (Fig. 6). This mosquito is a competent host for *D. immitis*, with a rapid development to infective L3. However, it is also a more aggressive and diurnal vector than our autochthonous mosquitoes (*Culex* spp.). Its presence may accelerate the geographical spread of heartworm disease, which is already the case in Italy, and, thus, could rapidly change the epidemiology of this parasitic disease in the South of France where it is only sporadic at the moment. It is worth noting that this mosquito plays a significant role in human medicine since it is the main vector of dengue and chikungunya viruses in subtropical areas.

Regarding sandflies, vectors of leishmaniosis, the situation is less clear. They are present as far as in Belgium, but the density and duration of the summer activity are key factors enabling leishmaniosis to become endemic or not. Climate may affect the duration of activity, but human actions, such as the creation of larval habitats for sandflies, also play an important part. Indeed, larvae develop in dark, wet and humus-rich areas (or moss) [29]. Refurbishing of exposed stone walls, garden walls, roadsides, fence walls enabled the creation of many “sandfly shelters” in the Southeast and Southwest of France. The risk of infection in dogs seems to have increased and the risk areas seem to have expanded. However, it is difficult to distinguish an effect of climate over human actions. If we consider today the distribution of *Phlebotomus perniciosus* in France, it is clear that the leishmaniosis risk area is no longer confined to the Côte d’Azur or to the Languedoc-Roussillon [28] (Fig. 7).

5. Impact of climate change on fleas

The impact of climate change on fleas is very difficult to assess, especially since the life cycle can occur throughout the entire year, including in winter, indoors. Nevertheless, annual variations are known and enable flea generations to succeed each other in the external environment from spring to fall. Thus, one can talk of flea years (like tick years), and of less favorable years. Climate changes resulting in humidity and optimal temperatures (temperature >25 °C;

humidity >85% RH) throughout the year were reported in Florida (USA) and Queensland (Australia) and some authors suggested that this may explain the continued heavy infestations of the cat flea (*Ctenocephalides felis*), observed by owners and veterinarians these past few years [30].

6. Conclusion

Climate change is a reality, studied by researchers and observed on a daily basis. The consequences on human and animal health have been extensively researched but, from now on, veterinary practice may be more and more concerned, especially with the diagnosis of parasitic diseases or diseases in areas where they usually do not occur, or with more frequent diagnosis. However, not any epidemiological modification should be linked to climate change, since many other factors are involved and often even overriding [31,32]. The veterinary practitioner will become, by his ability to identify these diseases, a key sentinel for future epidemiological changes [6]. Finally, we all have in mind, with regard to the more or less recent news, vector-borne diseases affecting production animals, such as the epizootic spread of ovine catarrhal fever or that of Schmallenberg disease. And yet, climate change was not the cause in both of these examples of emerging vector-borne diseases. The vectors are indigenous *Culicoides* midges, competent for exotic pathogenic agents newly introduced through human activities.

It should therefore be kept in mind that vector-borne diseases affect all production and companion animals or wildlife, and possibly humans, and that the factors that preside over their emergence or over the epidemiological modifications are often numerous.

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